EPSC Abstracts
Vol. 13, EPSC-DPS2019-905-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

The Global Basemap of Asteroid (101955) Bennu

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Abstract

Image mosaics are foundational data products, and often serve as basemaps for geological mapping efforts that investigate the spatial and temporal relationships across planetary surfaces. For the OSIRIS-REx mission, the global basemap also aides in determining a suitable sample collection site on asteroid (101955) Bennu. In this context, high-resolution, orthorectified, cartographic image basemaps are an important product to determine the relative sampleability, safety, and science value of potential sites on Bennu. Here we present the first panchromatic basemaps of Bennu derived from data acquired by instruments onboard NASA's OSIRIS-REx spacecraft.

1. Introduction

The primary objective of the third New Frontiers mission—Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx)—is to return a pristine sample of at least 60 kg from the surface of asteroid (101955) Bennu [6]. The Baseball Diamond (BBD) imaging campaign [3] during the Detailed Survey mission phase was designed to image > 80% of Bennu's surface with < 5.25 cm pixel scale using the OSIRIS-REx Camera Suite (OCAMS) [7] PolyCam and MapCam cameras. Data for the BBD campaign were acquired from a distance of ~3.7 km to Bennu, with a near constant local solar time of 10:00 am (–30°). Table 1 summarizes the observing conditions of 7,248 PolyCam images collected so far. The average pixel size for the PolyCam images is ~5 cm. We selected a subset of images that have similar phase angles and sufficient overlap to ultimately produce well registered, orthorectified cartographic mosaics of Bennu's surface. At 5 cm/pixel, this mosaic represents the highest-resolution global basemap that has been constructed of a planetary surface to date.

Creating cartographic basemaps for small irregular bodies, such as Bennu, presents challenges [3]. We are using a series of moderate to very high-resolution digital shape models [1] in geometric calculations and orthorectified projection of individual images to create two basemap products: 1) uncontrolled maps, which serve as a benchmark and use *a priori* spacecraft position and orientation, and 2) controlled maps, where a least squares bundle adjustment is applied to correct position and orientation errors that will ultimately register overlapping images on a global scale.

Table 1. Observing conditions of 7,248 PolyCam images acquired during Detailed Survey Baseball Diamond flybys 1 to 7.

Data	Min	Max.	Average	StdDev
Phase	20.65	55.75	38.71	7.85
Incidence	4.3	123.8	52.65	20.93
Emission	0.0	99.8	38.85	18.1
Resolution	0.038	0.07	0.05	0.0098
Local time	0.05	22.65	10.54	2.3

2. Methodology

We produced a custom version of Integrated Software for Imagers and Spectrometers (ISIS3) [3] which applies specialized cartographic mapping capabilities for small, irregular bodies. We derived new camera distortion models for the PolyCam, MapCam and SamCam instruments and added them to ISIS3. These new distortion models, particularly for each focus position of the PolyCam, improve the feature registration and mapping of adjacent overlapping images to minimize seams.

We selected a subset of 1,993 of the 3,125 PolyCam images controlled from the data collected during the BBD observation campaign for a global basemap. The images possessed a phase angle range of 30° to 55°, pixel resolution of 0.5 cm to ~5 cm, and a local solar time near 10:00 am. Table 2 shows the observing conditions for the images selected for these map products.

We used the ISIS tool *jigsaw* to correct initial *a priori* spacecraft pointing and position provided by the NAIF SPICE ephemeris kernels for each image [4]. We constructed a network of control points identifying common surface features for all images in the dataset. The control points were created using processes designed to match common surface features identified in all overlapping image areas.

Table 2. Observation conditions of 1,993 PolyCam images selected from BBD flybys 3 and 4 for the basemap.

Data	**Min.**	**Max.**	**Average**	**StdDev**
Phase	30.1	54.54	42.4	8.65
Incidence	27.55	90.0	50.28	18.01
Emission	0.0	54.73	19.5	12.7
Resolution	0.045	0.05	0.047	0.0011
Local time	1.04	10.35	9.84	0.74

We used the Bennu shape model to establish a ground truth resource for the network. We selected well-identified surface features on the shape model and created ground control points in the network that affix absolute body coordinates to these features. The points are locked to restrict adjustments to these points in the bundle adjustment.

Using this network, *jigsaw* applied a least squares bundle adjustment before orthorectified projection to various standard map projections using shape models with the highest-available resolution.

Each image was photometrically corrected to a standard 30° phase model and a disk function [5] before adding them to the mosaic.

3. Results

We produced a global control network composed of 3,125 images, 792,237 control points, and 3,256,136 control measures. The *jigsaw* tool applied a least squares bundle adjustment to this network to correct spacecraft pointing and position ephemeris. Camera angles were restricted to 0.2°, spacecraft position limited to 20 m, of adjustment and radius uncertainty limited to 50 m.

The *jigsaw* solution converged with a control point root mean sigma (RMS) 6.7 cm, and average image residual of 0.07 pixels with a maximum of 0.13 pixels. We updated spacecraft pointing and position in preparation to create basemaps at 5 cm resolution. We projected images with the corrected ephemerides onto a shape model to produce the global basemap.

The global basemap of Bennu is currently being used to search for the presence of hazards at candidate sample sites across the asteroid [2], and also for morphometric mapping of geologic features, such as boulders, craters, and thermal cracks.

4. Conclusions

The techniques and procedures developed for the production of this basemap will be applied to subsequent planned products which will be used to fully characterize the surface properties of Bennu. This approach also provides the basis for production of color image maps to study the spectral properties of potential sample collection sites. Future research includes improvements in establishing ground control with shape models and other suitable topographic resources, investigate ways to improve feature matching, develop efficient control network procedures, and apply this work to other small bodies.

Acknowledgements

This material is based upon work supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program.

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